Multi-Functional Materials for Defense

DoD Perspective on Sensing

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TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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DoD Perspective on Sensing

Issues in the Background

- Data to Decision vs. Big Data
- Mission Scope
- Budget

What Does This Mean for Sensing Research?

- We Need to Rethink How We Do Sensors

DoD Perspective on Sensing

What Do We Need?

1. **Intelligent Hardware**
   - **A System that Facilitates Decisions**
   - **Adapts Dynamically**
2. **Application Specific Hardware**
3. **Multi-Functional Materials for Defence**
   - **Not multiple applications per se**
   - **Multiple functions per material**
   - **Enable Intelligent Hardware**

DoD Perspective on Sensing

Goals for Today:

1. Collaboration

2. Innovate

3. Motivate

Micro and Nano Sensors Team

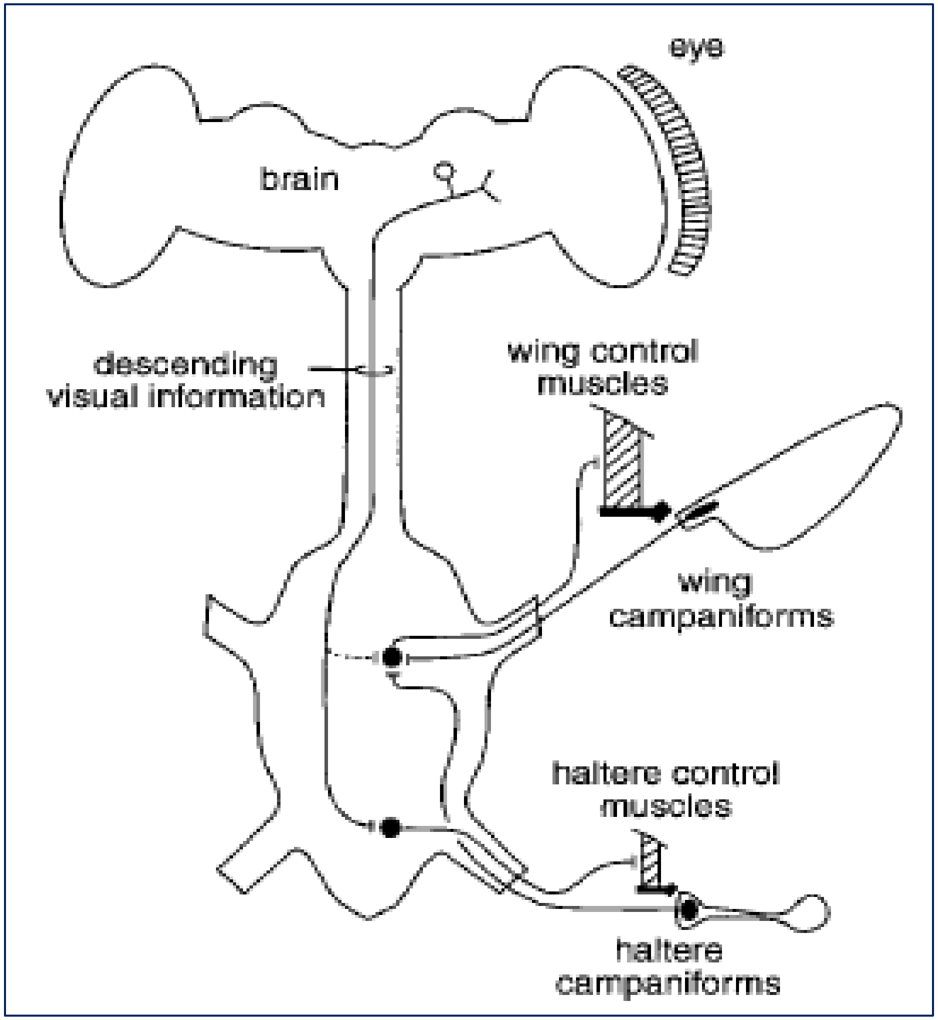
- Alma Wickenden (ARL)
- Joe Conroy (ARL)
- Vishnu Ganesan (Case Western)
- Kesshi Jordan (UC-Berkeley/San Francisco)
- Alec Koppel (U Pennsylvania)
- Yuan Chen (Princeton)
- Nick Perkons (Harvard)
- Daniel Silversmith, Kathryn Schneider (U Maryland)
- Michael Roberts (U Maryland BC)
- Michael Comparetto ()

Overview

- Cyber Physical Sensing and Control
  - Robotics
  - Human Physiological Monitoring
  - Piezo-MEMs
  - CMOS MEMs

- Collaboration Opportunities

Bio-Plausible Control Model



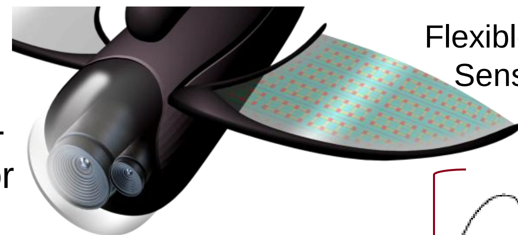
Cyber Physical Sensing & Control

Long Term Research Goals:

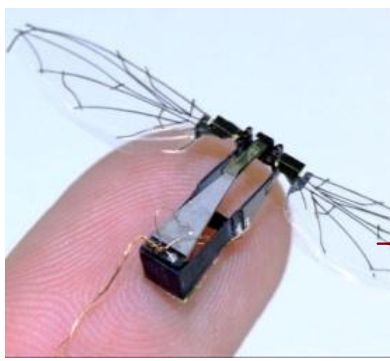
Implement sensor integration logic modeled after efficient biological systems for revolutionary, optimized coordination of varied physical and computational elements in fidelity-constrained, extremely low power sensor systems.

Program Objectives:

- Develop & implement bio-plausible control theory for power efficient, reflexive mm-scale robot control & sensor array information management
- Design, fabricate & test bio-/neuro-inspired MEMS/NEMS sensor modalities with minimized processor requirements
- Determine multisensory perception models suitable for decision making for autonomous small scale system operation & human/machine interfaces

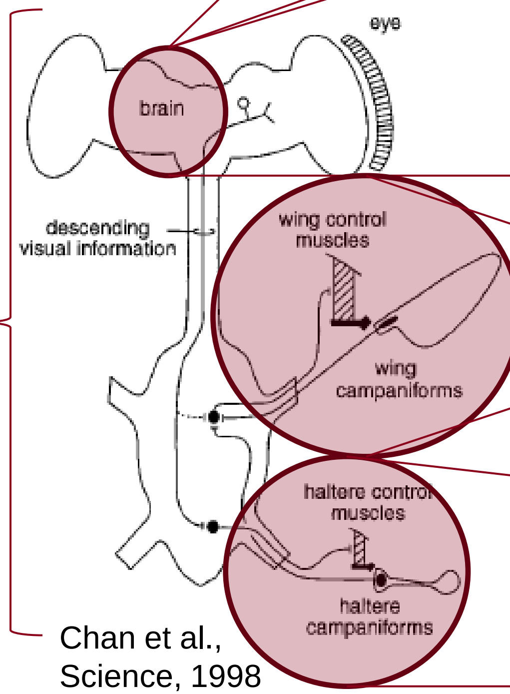


Flexible Electronic Sensor Arrays

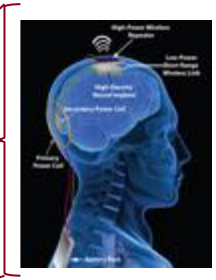


Rob Wood, Harvard/MAST

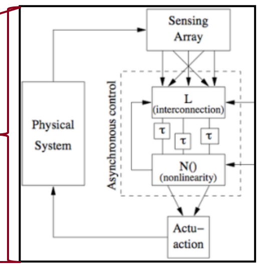
High Density Multifunctional Neuroimaging Sensor Arrays



Chan et al., Science, 1998



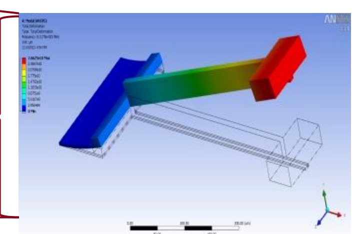
Multi-sensory perception



“Slow-computing” algorithms, Richard Murray, Caltech/ ICB

ARL Piezo Wings (fruitfly-scale)

FY09-10 DRI



FY11 DRI

Power efficient, reflexive multi-sensory processing will increase the adaptability, autonomy, functionality, reliability, and efficiency of various Army-relevant power- and size-constrained systems.

Autonomous Systems Enterprise

UNCLASSIFIED

Autonomous System Technologies provide the Soldier with superior situational awareness in mounted and dismounted operations

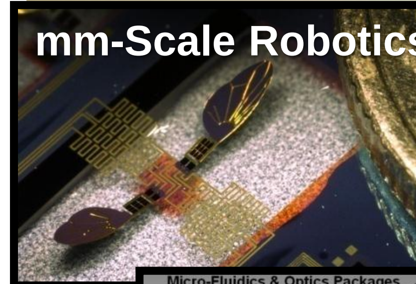
Autonomous Systems Enterprise

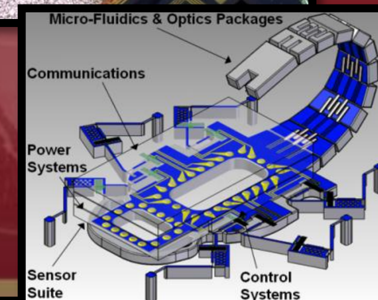
Severely Size, Weight, Power and Processing Constrained:

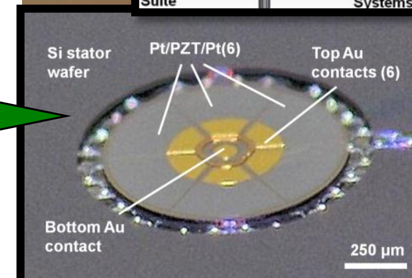
- Comprehensive Reexamination of Systems
- System Integration
- Novel Sensors
- Power Conversion
- Mobility Constraints
- Physics at the Small Scales

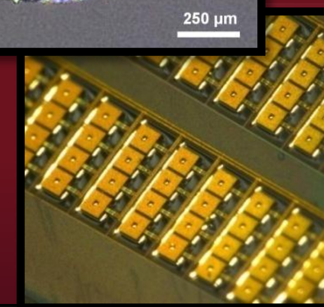
Requires a Paradigm Shift to Integrated Microelectronics

Micro-Autonomous System Technologies breeding a new class of Soldier assets



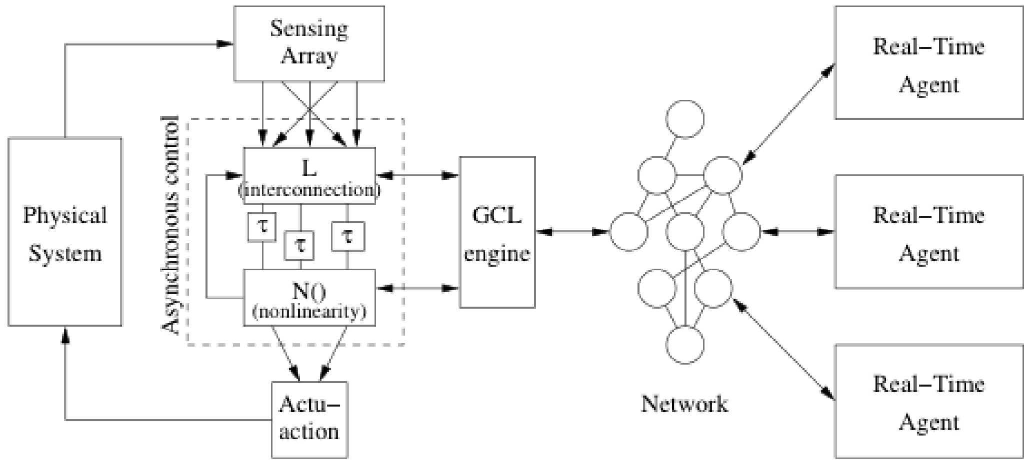






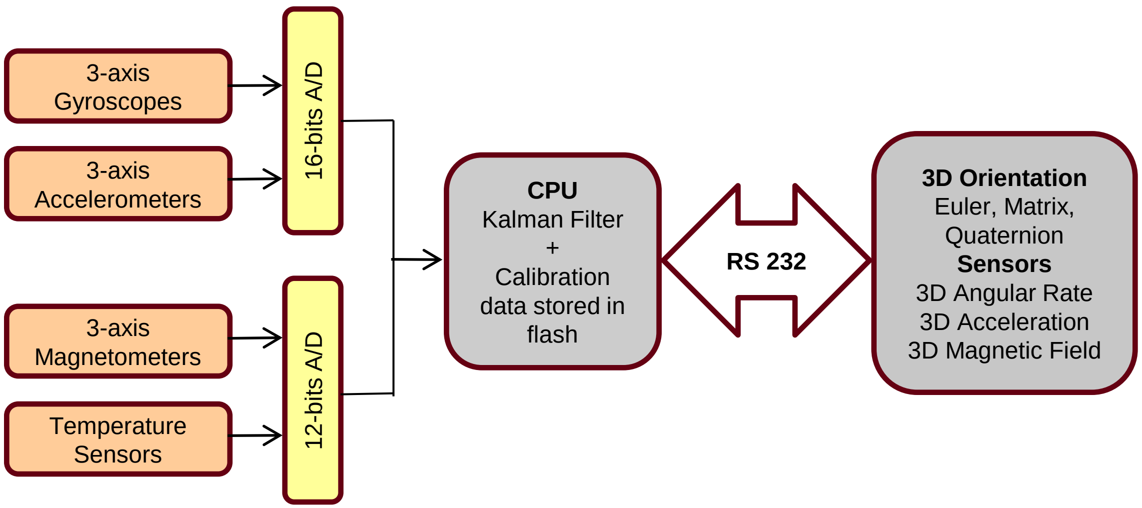
Autonomous System Technologies provide the Soldier with superior situational awareness in mounted and dismounted operations

Cyber Physical Sensing & Control



Potential advantages: Parallel, asynchronous processing, simplified logic applied where appropriate

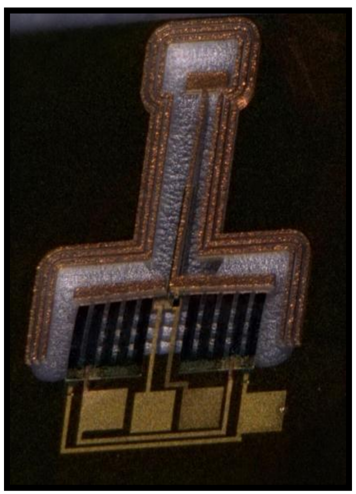
Caltech Parallel, Asynchronous "Slow Computing" Logic



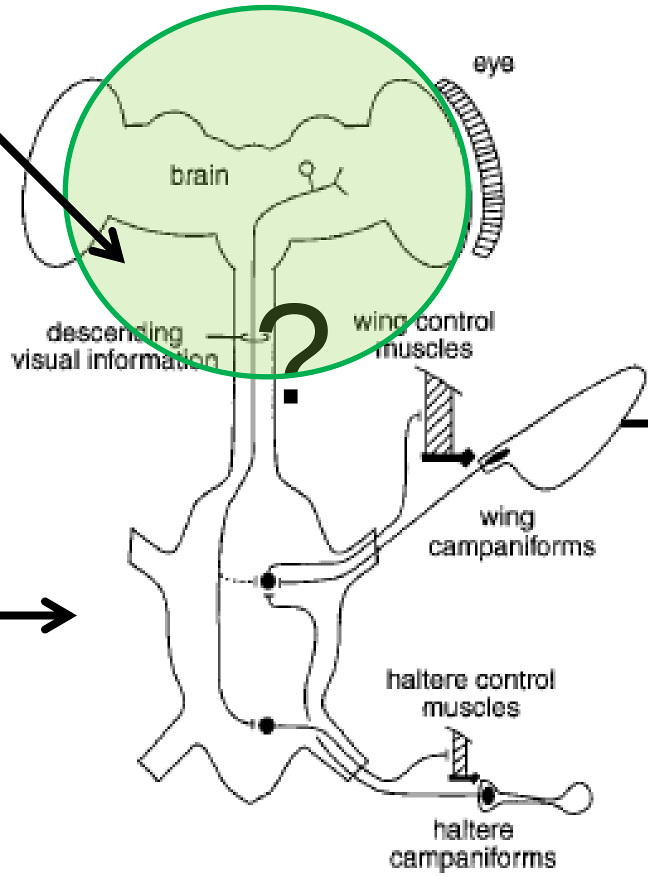
Known limitations: Large, high power, limited sensor input formats, data exchange limits (time, bandwidth)

Standard Serial Control Logic

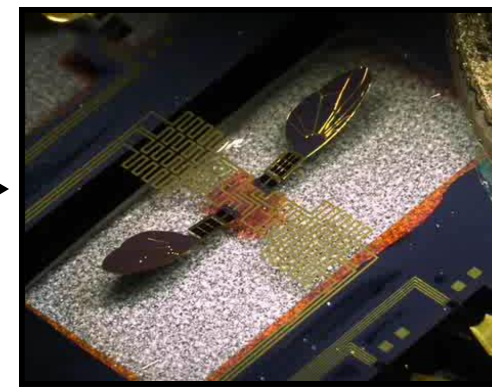
Big Picture



Sensors



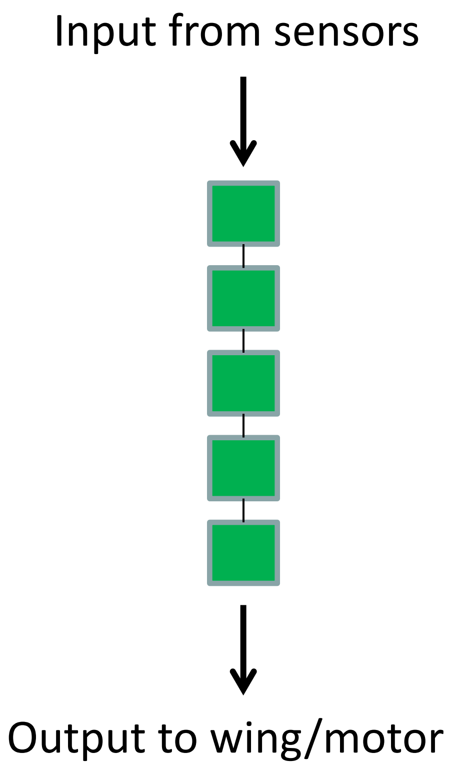
Control



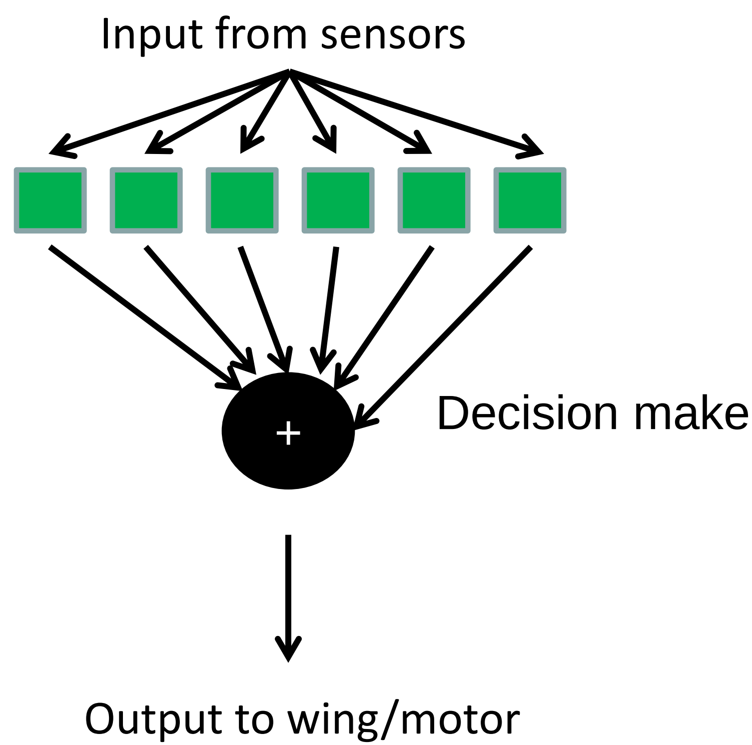
Actuation

Slow Computing

Traditional – requires fast, high power processors



Slow computing – parallel processing with low power, slower processors for fast control

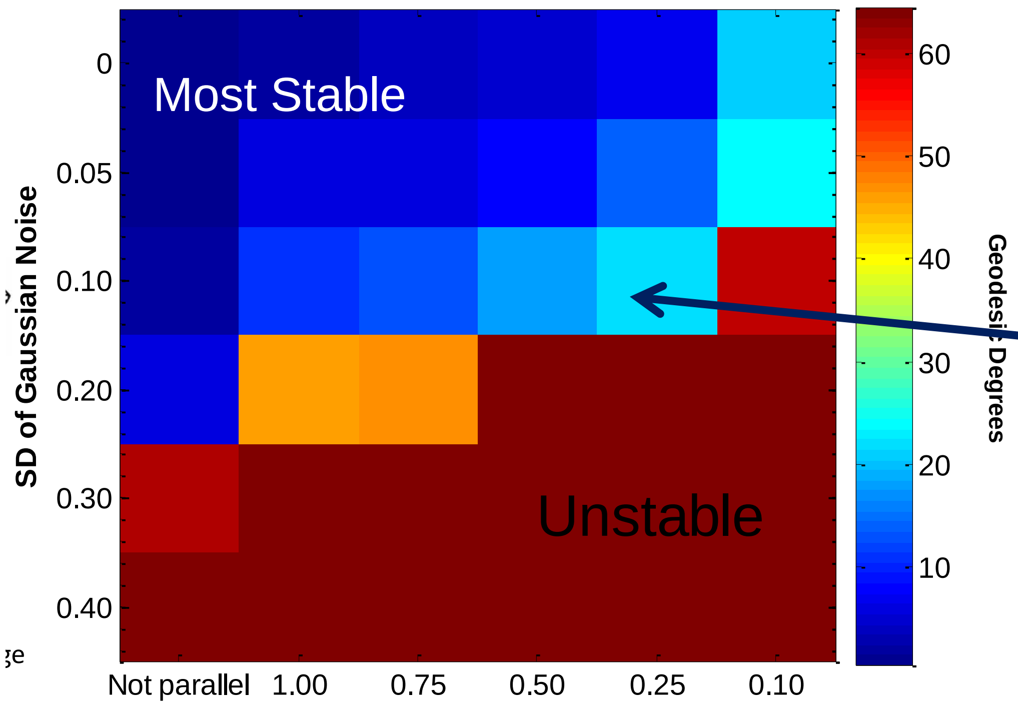


Richard Murray

Results

Band of Attitude Stabilization in Geodesic Degrees

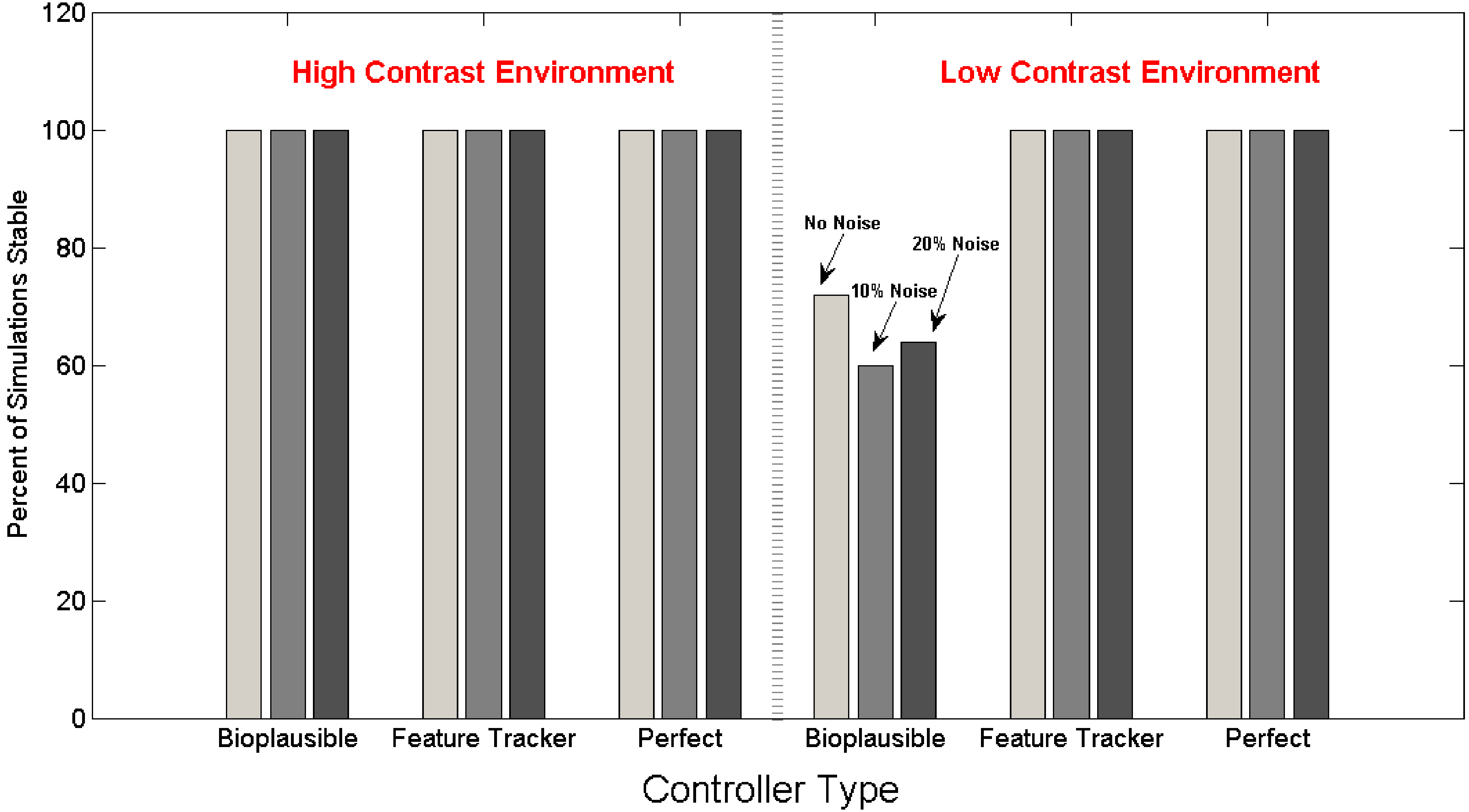
More Noise



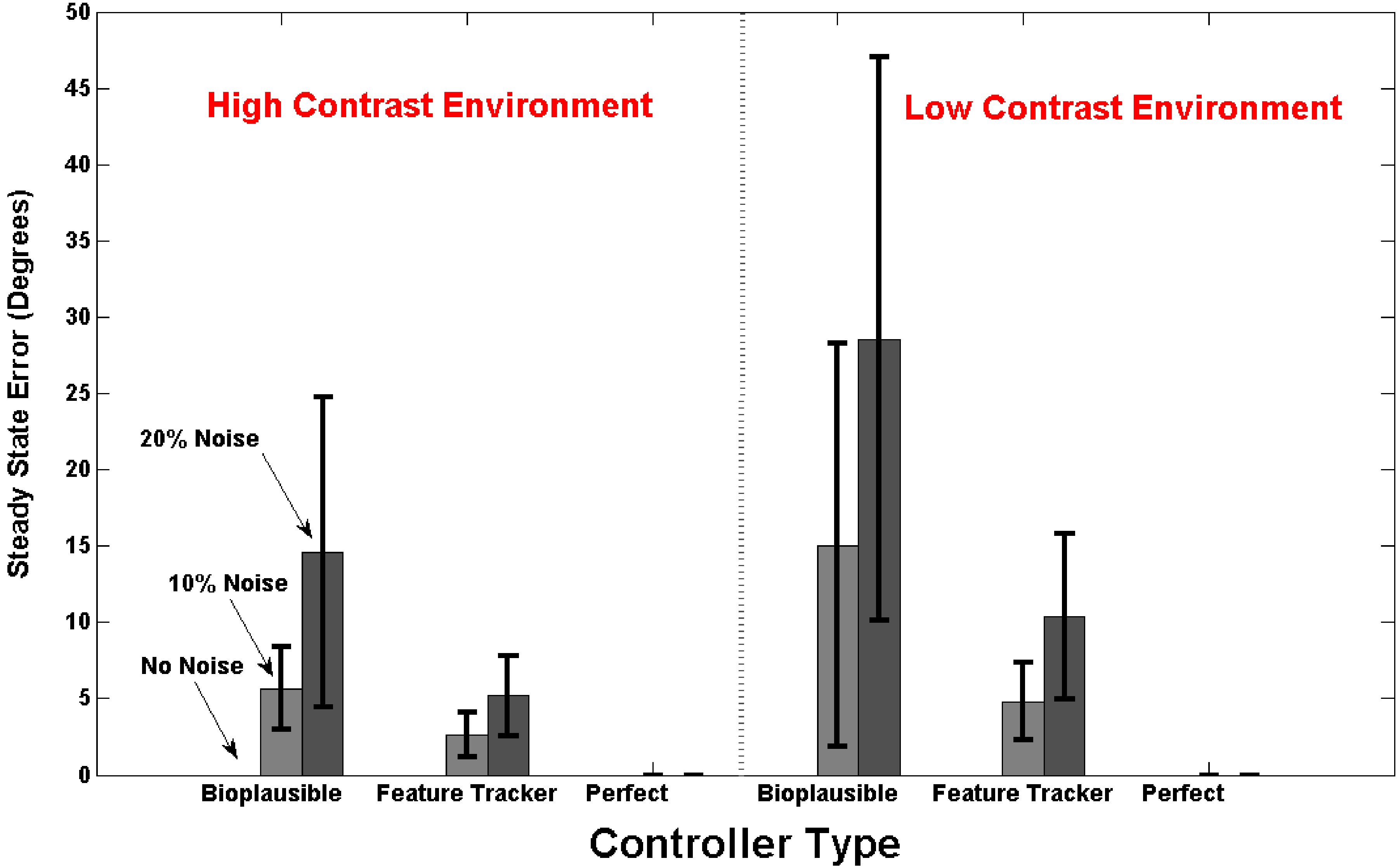
Region to operate our systems

Less information, faster decisions

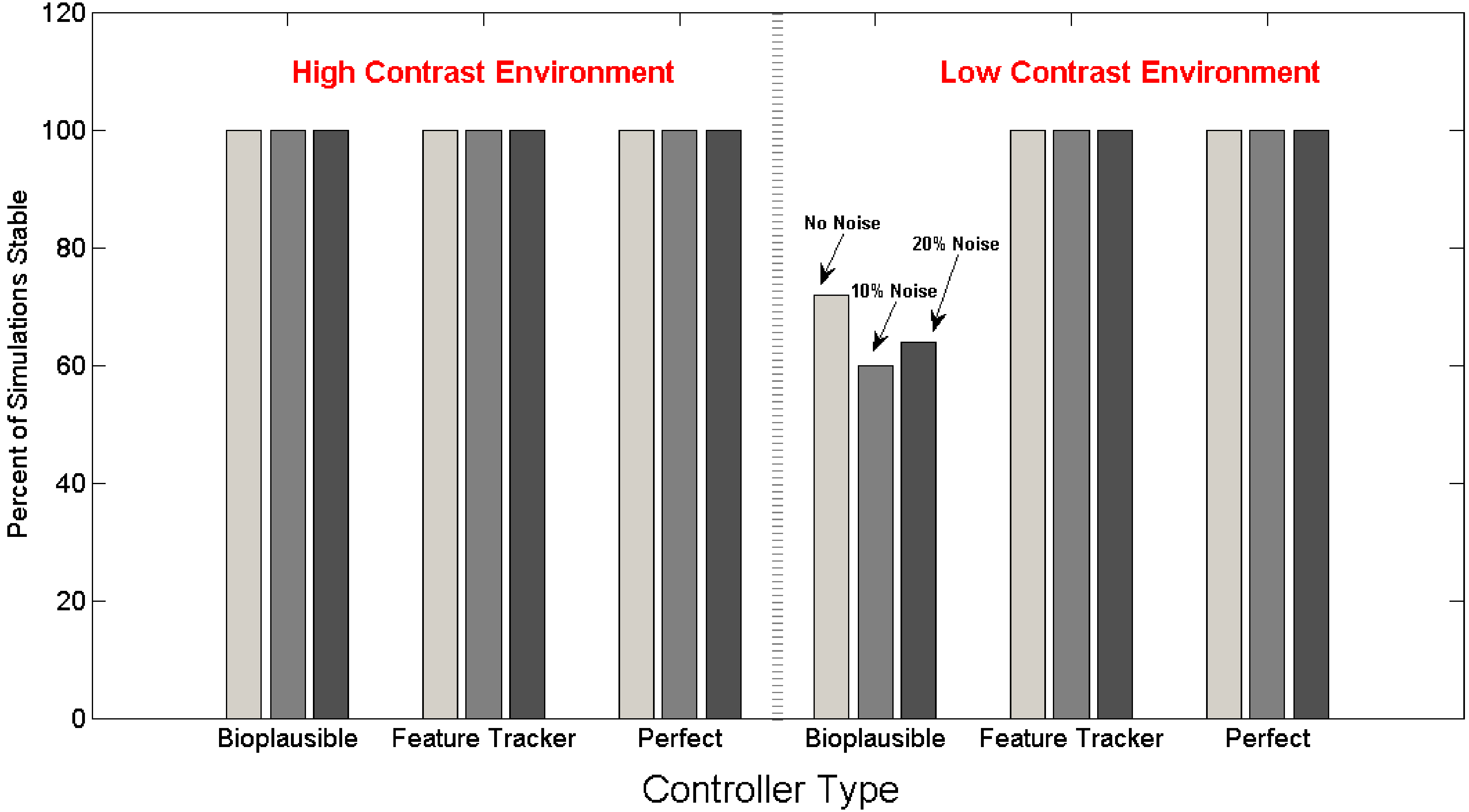
Results: Contrast and Noise



Results: Steady State Error

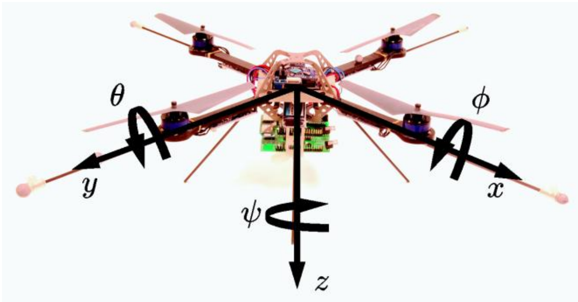


Results: Contrast and Noise

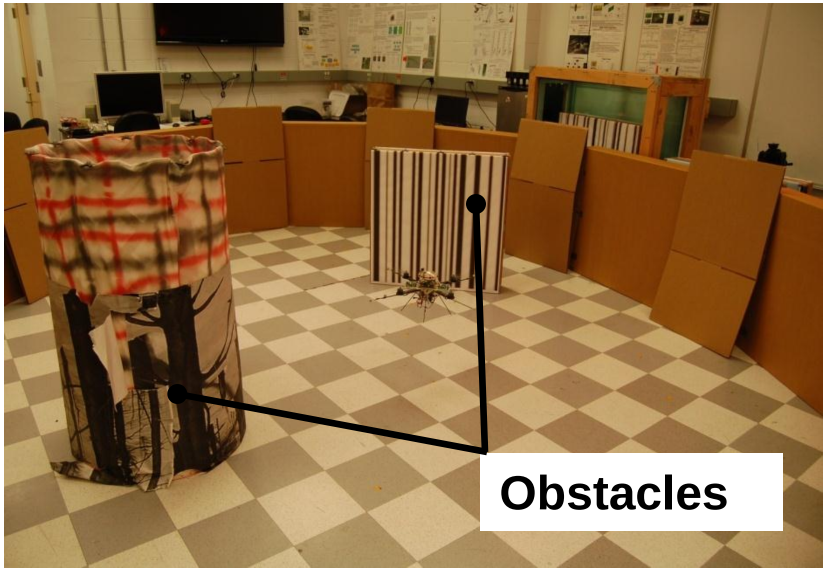


Structure From Motion

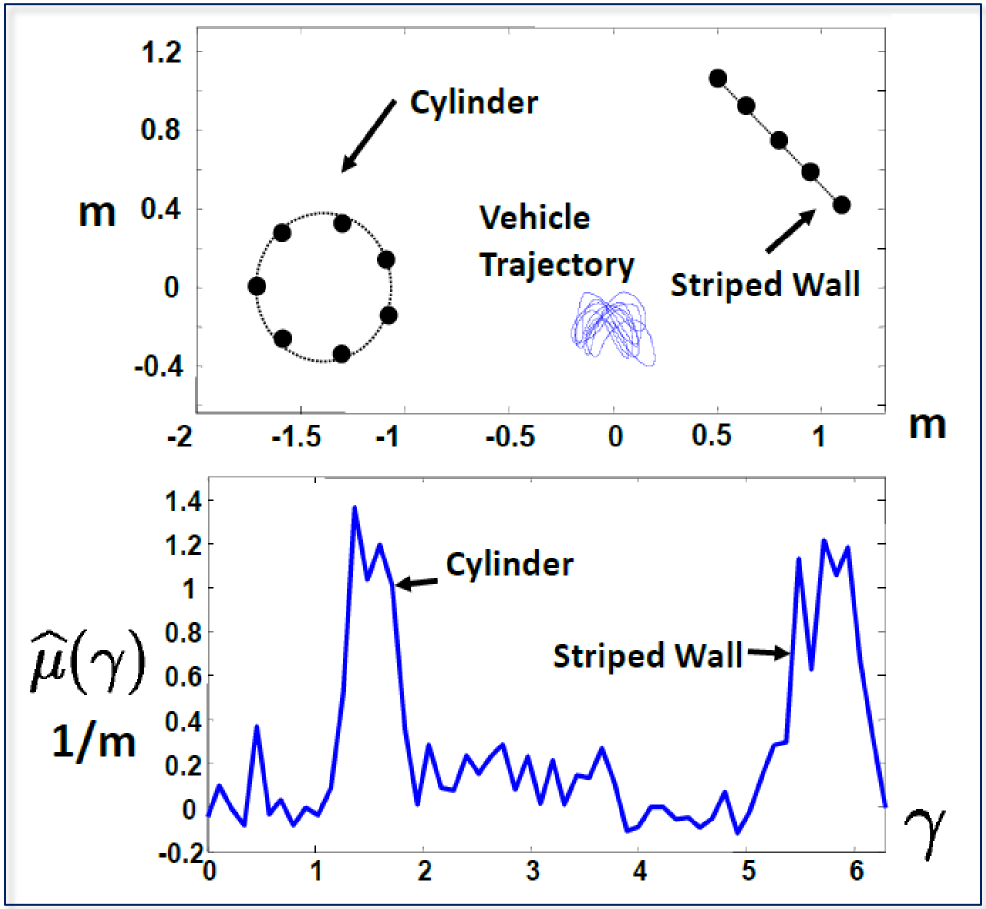
Flight Vehicle



Test Arena



Feature Extraction



Wearable EEG Development and Testing (WDT)

STATUS QUO

The current neuroimaging modalities do not allow assessment of brain activities of participants performing tasks involving natural movements

Severely limits neuroergonomic studies and applications in real-world environments

NEW INSIGHTS

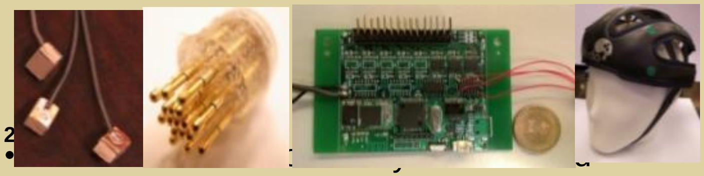
EEG might allow freedom of movement of the head and body, but requires advanced on-line signal-processing algorithms to correct movement artifacts

Barrier Addressed:
To solve the lack of portable, user-acceptable, and robust systems for routinely monitoring brain and body dynamics in complex real-world environments (B1, B2)

ACHIEVEMENT DESCRIPTION

2010 MAIN RESULT:

- Dry foam-based electrode
- Spring-loaded probe electrodes
- Wireless data acquisition (DAQ) circuit board
- EEG cap (MINDO 16 helmet) featuring 16 dry electrodes, miniature DAQ, and wireless telemetry
- Graphic user interface on mobile devices for data logging



- continue to improve the DAQ board
- Continue to improve the wearable and wireless dry-electrode (WWD) EEG system
- Modify the MINDO 16 for the HD-Cog TX17 experiment at ARL
- Evaluate the quality of signals acquired by the WWD EEG system
- Test feasibility of using the WWD EEG system to assess cognitive-state of operators in MVS
- Develop signal-processing approaches for on-line artifact removal

END-OF-PHASE GOAL

A wireless, wear-and-forget human machine interface that can allow assessment of brain activities of unconstrained participants within real operational environments

Transition:
MoBI for detecting changes in vehicle operator alertness and performance (TE 1). Advanced tools for MoBI and neurocognitive performance assessment (TE 2 C4)

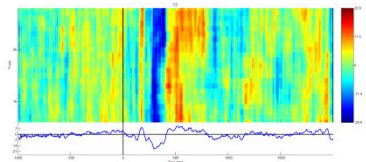
COMMUNITY CHALLENGE

Can we augment human performance through the WWD EEG monitoring and processing?

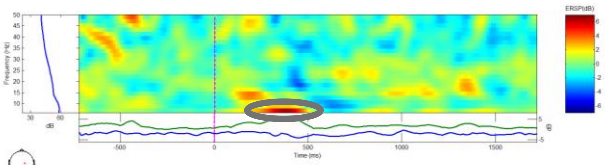
WWD EEG systems are easily donned and doffed for cognitive monitoring in real-world environments

EEG Filter Design for Near-Real-Time Signal Processing

- **CHALLENGE:** The low signal-to-noise ratio and inconsistencies due to inter- and intra-personal variation of electroencephalography (EEG) data prohibits system use outside of a controlled laboratory environment.
- **GOAL:** Develop a filter that allows real-time, frequency-specific analysis of EEG data for the practical study of soldier cognitive function on a single-trial basis.
- **APPROACH:** Investigate filtering methods including simple and multistage band-pass filters and several transforms (Fourier, Hilbert, and Wavelet) using MATLAB simulation and testing to determine the optimal filter design.
- **INITIAL RESULTS:**
  - Adaptive filter produced comparable results using 10 events to current neuroscience method using 32 events.
  - Simulated real-time filtered data can identify some obvious P300 responses on single-trial, but waveform is not consistent enough for real-time analysis by visual inspection.
  - The root mean square deviation values are insufficient to evaluate filter performance.

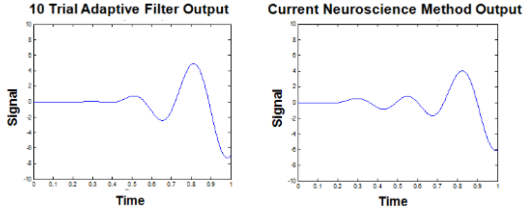


The result of band-pass filtering 1 – 100 hz and averaging over 32 events



By narrow band-passing the low frequencies (circled), the SNR is greatly improved.

- **FUTURE WORK:**
  - Further processing is required to yield generalizable results
  - Validation with known EEG classifiers



Active Research Areas

- Miniaturization of EEG electrodes and haptic sensors
- Biocompatible reversibly adhesive EEG electrodes (“gektrodes”)
- Flexible electronics for sensors

Enable robust, in-battlefield detection

- Bioplausible, multisensory control/decision making algorithms
- Development of robust fMRI sensors
- Self-organizing sensor arrays

Enable enhanced sensing and information processing in noisy environments

Flexible electronics research, John Rogers Group, UIUC

Future Collaborative Research Areas

- Novel Sensors:
  - Miniaturization of EEG electrodes and haptic sensors
  - Biocompatible reversibly adhesive EEG electrodes ("gektrodes")
  - Stretchable electronics for sensors
  - Development of robust fMRI sensors
  - Self-organizing sensor arrays

Enable robust, in-battlefield detection

- Bioplausible, multisensory control/decision making algorithms
  - Autonomous Systems
  - Human Physiological Monitoring
  - Computationally efficient algorithm development for robust, noisy applications

Enable enhanced sensing and information processing in noisy environments

- SOAR
  - CyberPhysical Sensors and Control
  - Adaptive EEG

Collaboration Opportunities

- Research of Potential Interest
  - Cyber Physical Sensing and Control
    - Robotics
    - Physiological Monitoring
  - Piezo-MEMs
  - CMOS MEMs
- Facilities
  - Clean-Room Foundry
  - Characterization Facilities
  - Robotics Experimental Facilities
- Mechanisms
  - CQL
  - SMART
  - SOAR
  - NSF
  - Guest

Awards

8. Wind Science and Engineering Research Center
Texas Tech University
Career: Atmospheric scientist
Learn to: Measure hurricane damage. Students collect data about hurricanes and tornadoes by firing debris out of a cannon.
[PopSci Sept. 2007]

9. WOODS HOLE OCEANOGRAPHIC INSTITUTION
Woods Hole, Massachusetts [page 47]

10. Game Design Initiative
Cornell University
Career: Videogame designer
Learn to: Create your own game at the first Ivy to offer a minor in game design.
[PopSci Sept. 2008]

11. DIVISION OF GEOLOGICAL AND PLANETARY SCIENCES
California Institute of Technology [page 47]

12. Peruvian Amazon Field Course
New College of Florida
Career: Rainforest biologist
Learn to: Follow rare animals up 150-foot trees. With tree-climbing pioneer and ecologist Meg Lowman, students tag animals and survey biodiversity. [PopSci Sept. 2010]

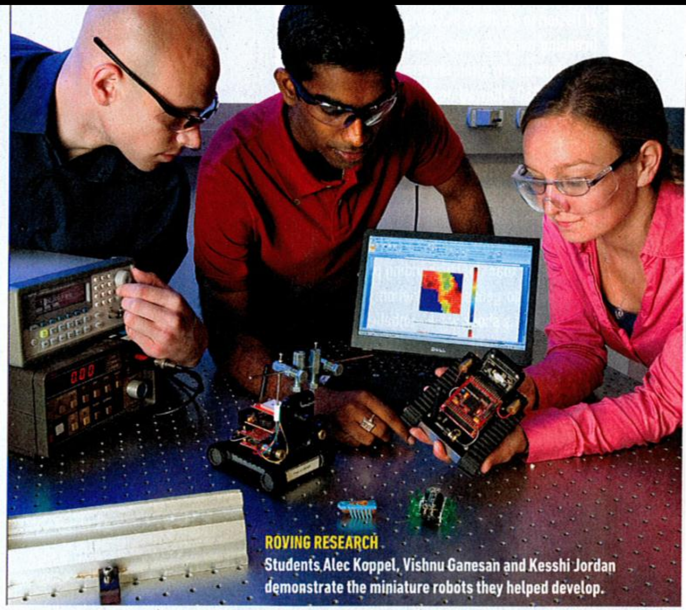
13. U.S. ARMY RESEARCH LABORATORY
Adelphi, Maryland

14. Toy Lab
Massachusetts Institute of Technology
Career: Toy designer
Learn to: Build toys. Teams of six get a theme and $750 for a prototype.
[PopSci Sept. 2010]

15. REED NUCLEAR REACTOR
Reed College [page 50]

16. Lightning Research Lab
University of Florida
Careers: Physicist, engineer
Learn to: Catch millions of volts from the sky by using rockets to draw lightning during passing storms. [PopSci Sept. 2007]

Popular Science 2011 Most Awesome Labs



ROVING RESEARCH
Students Alec Koppel, Vishnu Ganesan and Kesshi Jordan demonstrate the miniature robots they helped develop.

September 2011

DESIGN A MICRODRONE

13. U.S. ARMY RESEARCH LABORATORY, Aberdeen Proving Ground
Careers: Defense researcher, engineer

Some of the students interning on the Micro-autonomous Systems Technology (MAST) project at the Army Research Lab in Maryland spend their summer trying to equip soldiers with dozens or even hundreds of "insect" robots that can swarm into a bunker or cave to provide a remote look inside. "Working in silicon at the fruit-fly scale, they'll cost almost nothing," says Chris Kroninger, an aeronautics researcher specializing in MAST's wings, "and they can be equipped with limited sensor capability that can be a first warning for a soldier."

Kroninger says the robots won't be deployed for another decade at least, and there's plenty of work yet to be done. That's true of most projects given to the 185 undergraduate students at the Army Research Lab every year. Whether they analyze body armor, develop new materials, or create miniaturized sensors, there's more going on than they can possibly be part of.

"A lot of these kids come in with a deer-in-the-headlights look," says 26-year-old researcher John Gerdes, who was an intern in 2006. "But the ARL does such a good job of balancing realistic expectations with the proper amount of mentoring and resources, it's almost impossible not to succeed."

Aaron Harrington came to the ARL as a University of Maryland sophomore and wound up spending two more summers there. "I didn't know that research was something that you could go into," says Harrington, who is now 24 years old and earning a master's degree in aerospace engineering from his alma mater. In 2008, Kroninger assigned him to photograph wings flapping, which normal cameras will capture only as a blur. Using a strobe light to combat the blur and a technique called photogrammetry, Harrington used two cameras recording video at 30 frames per second. "If you had two cameras and knew how far apart they were and had some idea of the distance from the test bay," he says, "you could use triangulation to measure the distance. It turned out to be very accurate."

Things I Wished I had Said

We are Standing on the Cusp of a Substantial Paradigm Shift in How We Collect, Analyze, and Act Upon Data

- **How do we collaborate to better to achieve this?**
- **Are there any innovative approaches?**
- **How do we motivate a concentration in research?**